

HOME RANGE, REPRODUCTION, AND SURVIVAL OF THE DESERT KIT FOX,  
SOUTHEASTERN, CALIFORNIA

A Dissertation

by

CHARLES JACK RANDEL, III

Submitted to the Office of Graduate and Professional Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Nova J. Silvy
Committee Members,	William E. Grant
	Louis A. Harveson
	Rodney L. Honeycutt
	X. Ben Wu
Head of Department,	Michael P. Masser

August 2015

Major Subject: Wildlife and Fisheries Sciences

Copyright 2015 Charles Jack Randel, III

## ABSTRACT

Kit foxes (*Vulpes macrotis*) are small, nocturnally active, arid-land foxes found in semi-arid and desert climates in western North American and northern Mexico. Two kit fox subspecies: the federally endangered and state threatened San Joaquin kit fox (*V. m. mutica*) and the desert kit fox (*V. m. arsipus*) occur in geographically distinct ranges in California. The majority of kit fox research has focused on the San Joaquin kit fox due to its state and federal status, with relatively few studies conducted on California's desert kit fox populations, a fully protected species in California.

A 2-year radio-telemetry study of the desert kit fox was conducted to determine the following life history traits: home range, home range overlap among individuals, population density, reproductive parameters, seasonal and annual survival, and cause-specific mortality sources in the Upper Chuckwalla Valley, Riverside County, California.

Fifty-six desert kit foxes were captured and fitted with mortality-sensitive radio-collars and tracked from October 2012 to August 2014. Individuals were located 5–7 times per week, and nightly locations were used to estimate seasonal and annual fixed kernel and minimum convex polygon home range size, seasonal and annual survival, and mortality location and dates. Additionally, radio-telemetry was used to identify natal den complexes for direct monitoring, to determine reproductive success, and to obtain litter size.

Based on 95% fixed kernel or MCP estimators There was no difference ( $P = 0.820$ ) between home range sizes of males and females, with mean home range sizes of

$15.77 \pm 1.03 \text{ km}^2$  (95% fixed kernel) and  $18.48 \pm 1.77 \text{ km}^2$  (MCP), respectively. Similarly, there was no statistically significant difference in seasonal (e.g., pair formation [ $P=0.855$ ], pup-rearing [ $P=0.205$ ], and dispersal [ $P=0.180$ ]) home range sizes based on sex or year. Annual home range overlap was significantly larger for mated pairs ( $79.3 \pm 1.35\%$ ) than unmated pairs ( $20.9 \pm 1.01\%$ ), and this is consistent with patterns for other populations of other kit foxes. Densities in the study area were  $0.18 \pm 0.05/\text{km}^2$ . Reproductive success in 2013 and 2014 did not vary, with 50% of females producing  $\geq 1$  pup annually. Mean litter size was  $2.69 \pm 0.30$  ( $SE$ , range 1–6) and mean reproductive rate was 1.35, with no statistically significant difference ( $\chi^2 = 0.001$ ,  $P = 0.97$ ) between years. Annual survival rates for desert kit fox ranged from 0.752–0.885, and survival rate was 0.674. Similar to previous studies, coyote (*Canis latrans*) predation was the primary source of mortality during this study.

Larger than average home range size coupled with a low reproductive rate may have been influenced by drought and the associated prey availability. Previous research of kit foxes in California's Central Valley and Utah's Dugaway Proving Grounds found both home range size and reproduction were influenced by prey availability, which is known to be adversely affected by drought conditions.

## DEDICATION

*Dedicated to the memory of Dr. Valeen H. Silvy*

## ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Silvy, and my committee members, Dr. Grant, Dr. Harveson, Dr. Honeycutt, and Dr. Wu, for their guidance and support throughout the course of this research.

I would additionally like to thank the California Energy Commission for funding the research under the Public Interest in Environmental Research grant program, the California Department of Fish and Wildlife for logistical support and permit issuance, as well as Mr. Bill Vanherweg and numerous field technicians for assistance during data collection.

## TABLE OF CONTENTS

	Page
ABSTRACT .....	ii
DEDICATION .....	iv
ACKNOWLEDGEMENTS .....	v
TABLE OF CONTENTS .....	vi
LIST OF FIGURES .....	viii
LIST OF TABLES .....	ix
CHAPTER I INTRODUCTION .....	1
RESEARCH OBJECTIVES .....	5
STUDY AREA.....	5
CHAPTER II HOME RANGE AND POPULATION DENSITY.....	8
METHODS.....	9
Capture and Marking.....	9
Telemetry.....	9
Seasonal and Annual Home Range .....	10
Home Range Overlap .....	10
Population Densities.....	11
RESULTS.....	11
Annual and Seasonal Kernel Home Range .....	11
Annual and Seasonal MCPs .....	14
Home Range Overlap and Population Density.....	19
DISCUSSION .....	20
Home Range Overlap .....	23
Population Density .....	24
CHAPTER III REPRODUCTIVE SUCCESS, RATE, AND MEAN LITTER SIZE....	25
METHODS.....	25
Capture and Marking.....	25
Reproduction .....	26
RESULTS.....	27
DISCUSSION .....	29
CHAPTER IV SURVIVAL AND CAUSE SPECIFIC MORTALITY.....	31
METHODS.....	32
Capture and Marking.....	32
Survival Estimation and Analysis .....	33

Mortality Determination.....	33
RESULTS.....	34
Survival .....	34
Cause Specific Mortality .....	35
DISCUSSION .....	36
CHAPTER V CONCLUSIONS.....	39
LITERATURE CITED .....	41
APPENDIX .....	48

## LIST OF FIGURES

	Page
Figure 1. Kit fox distribution in the United States and Mexico. ....	2
Figure 2. Distribution of the desert kit fox, California.....	3
Figure 3. Upper Chuckwalla Valley, Riverside County, California. ....	7
Figure 4. Desert kit fox radio-telemetry fixes October 2012-August 2014. ....	12
Figure 5. Percent 95% fixed kernel annual home range overlap for unmated and mated.....	19
Figure 6. Desert kit fox population density estimate over time .....	20
Figure 7. Desert kit fox natal den locations – 2013 and 2014.....	28
Figure 8. U.S. solar energy generation potential within the kit foxes distribution.....	32
Figure 9. Desert kit fox predation location.....	36



## LIST OF TABLES

	Page
Table 1. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual kernel core (50%) and home range (95%) estimates ( $\bar{x} \pm SE$ ; km <sup>2</sup> ), 2012–2013, southeastern California. ....	16
Table 2. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and 10-month kernel core (50%) and home range (95%) estimates ( $\bar{x} \pm SE$ ; km <sup>2</sup> ), 2013–2014, southeastern California. ....	17
Table 3. Kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual 100% MCP home range estimates ( $\bar{x} \pm SE$ ; km <sup>2</sup> ), 2012–2014, southeastern California. ....	18
Table 4. Female desert kit foxes monitored ( <i>n</i> ), reproductive success, mean litter size, litter size range, and reproductive rate, Upper Chuckwalla Valley, California (2013–2014). ....	28
Table 5. Survival estimates of radio collared desert kit foxes in southeastern California, 2012–2014. ....	35

## CHAPTER I

### INTRODUCTION

Kit foxes (*Vulpes macrotis*) are a small, nocturnally active, arid land species of fox occurring in the southwestern United States and northern Mexico (Figure 1; McGrew 1979). Throughout their range, kit foxes are associated with desert and semi-arid regions in either steppe or desert climates (McGrew 1979). There are five recognized subspecies of kit fox (O'Neal et al. 1987), two of which occur in California: the state and federally endangered San Joaquin kit fox (*V. m. mutica*) and the California desert kit fox (*V. m. arsipus*), which is fully protected. The two subspecies occupy separate and distinct ranges within the state with no population overlap. The desert kit fox's distribution encompasses the Sonoran and Mojave Deserts of southern Nevada, Arizona, and California (McGrew 1979). In California, the desert kit fox has a 101,800 km<sup>2</sup> distribution from southern Mono County, south to the Mexican border and from northwestern Los Angeles County east to the Arizona and Nevada borders (Figure 2).

Kit fox life history traits (e.g., reproduction, survival, mortality) and ecological parameters, such as home range (the area in which an animal normally travels and searches for food; Burt 1943) are highly variable both spatially and temporally. This variation in life history traits has been attributed to biotic (e.g., prey availability, predation, and competition) and abiotic (e.g., climate conditions and anthropogenic activity) factors (Arjo et al. 2007, Warrick and Cypher 1998). For example, home range estimates range from 3.4 km<sup>2</sup> in Utah (O'Neal et al. 1987) to  $14.2 \pm 1.9$  km<sup>2</sup> in western Arizona (Zoellick and Smith 1992), with home range overlaps varying based on

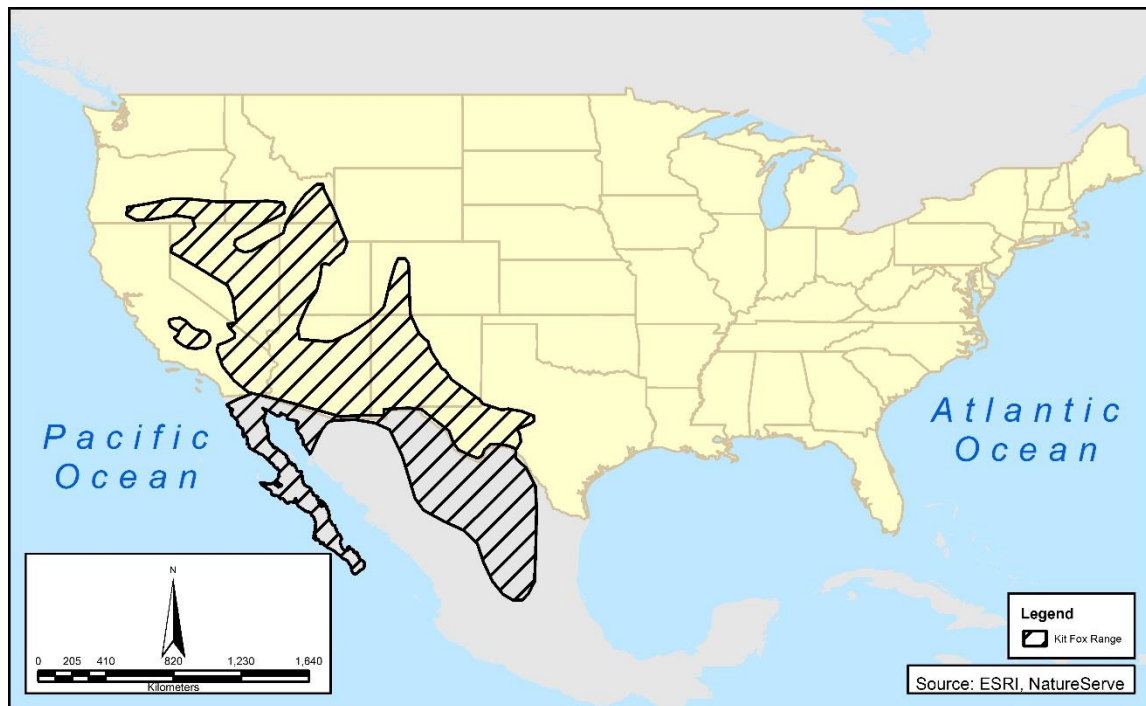


Figure 1. Kit fox distribution in the United States and Mexico.

pair bond status (e.g., paired or unpaired), population density, and prey availability (Zoellick and Smith 1992). Mated pairs exhibit the highest percentage of home range overlap (Zoellick and Smith 1992). Home range overlaps are non-exclusive areas of use within an individual's home range. When all range overlaps are known, the degree of home range overlap within a population can be used to determine population.

Kit foxes exhibit a socially monogamous mating system, which is characterized by long-term pair-bonds (Kleiman 1977), and individual members of the pair maintain distinct home ranges. The species is monestrous (Asa and Valdespino 2003), giving birth to a single litter of 1–7 pups annually (Ralls et al. 2007). Mating typically occurs in mid-winter (December to January) with pups whelped from mid-February to mid-March.

Pups are nursed below ground for approximately 4 weeks, with both parents provisioning pups until they are fully independent at 5–6 months of age (Ralls et al. 2007). Males provision lactating females until pups are weaned with both parents provisioning pups until they are fully independent (Egoscue 1962).

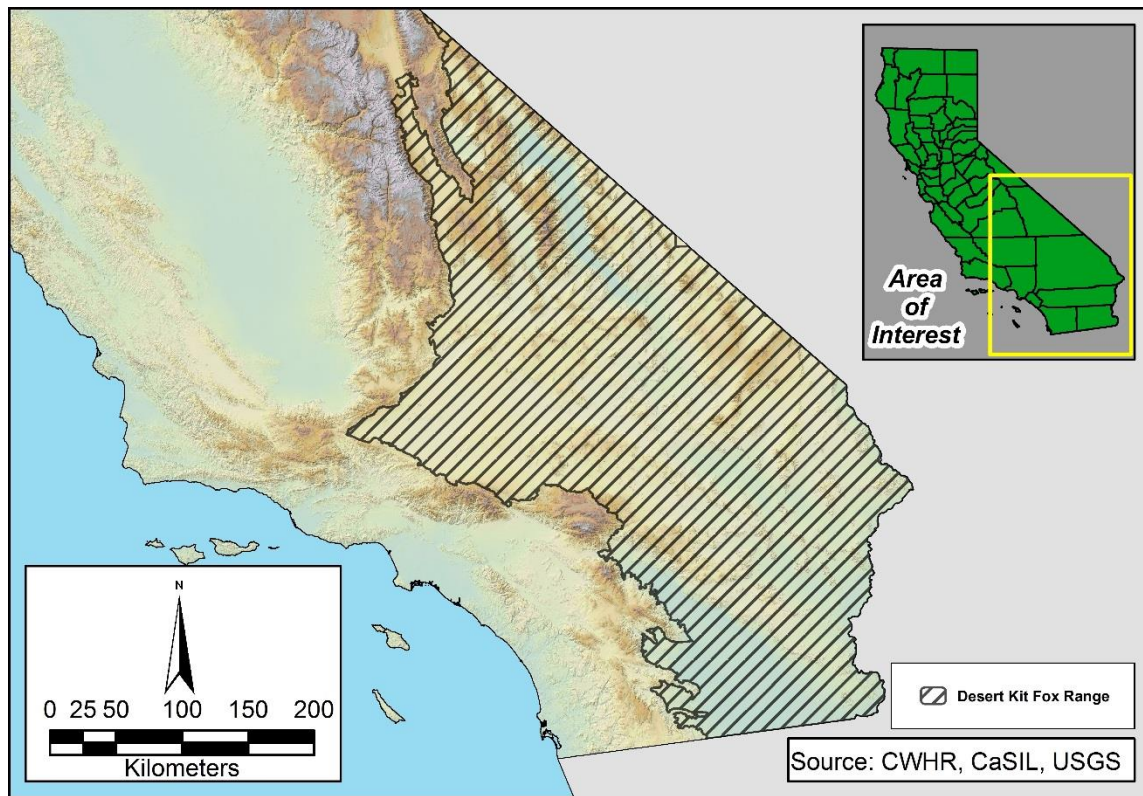


Figure 2. Distribution of the desert kit fox, California.

As with home range size, survival rates and reproductive rates vary significantly, both spatially and temporally. Annual survival estimates range from 0.35 at the Naval Petroleum Reserves in California (Cypher and Scrivner 1992) to 0.84 at the Lokern

Natural Area (Nelson et al. 2007). Predation is the most frequently cited source of kit fox mortality, with coyotes being the most common predator. Coyote predation of kit foxes is considered the strongest example of interspecific killing among North American carnivores (Palomares and Caro 1999). Vehicular strikes also are a significant mortality source for kit foxes in urban areas (Bjurlin et al. 2005), but rarely exceed 10 percent elsewhere and are not considered significant enough to influence population dynamics (Bjurlin and Cypher 2003). Infectious diseases, while present in kit fox populations, are not a significant mortality source (Cypher et al. 2000).

The North American range of the kit fox occurs in areas with high potential for solar energy development (Bird et al. 2005, Carlisle et al. 2014, Lopez et al. 2012), and concern over climate change has increased interest in this development within the range of the kit fox. Increasing development requires region specific life history and ecological data to assess and mitigate potential impacts to kit foxes.

Between 2004 and 2014, solar energy development has increased in California from 0.3% to 1.82% (California Energy Almanac 2014), with the majority of energy development occurring in the Mojave and Colorado Deserts of eastern and southeastern California, coinciding with the known range of the desert kit fox (*V. m. arsipus*) in California (Figure 2). In comparison to the federally endangered and California threatened San Joaquin kit fox (*V. m. mutica*), region specific data on the life history and ecology of the desert kit fox in California is limited.

## RESEARCH OBJECTIVES

The overall research objective was to quantify regional specific life history and ecological parameters of desert kit foxes in the Upper Chuckwalla Valley, Riverside County, California. This information will facilitate environmental assessments for proposed projects in California that will occur within the range of the desert kit fox.

Three chapters in this dissertation address these objectives. The chapters are:

1. Home range and population density (Chapter II)
2. Reproductive success, rate, and mean litter size (Chapter III)
3. Survival and cause specific mortality (Chapter IV)

A final chapter will summarize and discuss research findings. Chapters were prepared as independent papers and contain a degree of repetition in material presented.

## STUDY AREA

The study area (261 km<sup>2</sup>) was located in the Upper Chuckwalla Valley, Riverside County, California (33°43'N, 115°24'W) and bounded by the Eagle Mountains (west and north), Coxcomb Mountains (east), and Chuckwalla Mountains (south). Elevation ranged from 250–300 m above mean sea level, with topography generally sloping from the northwest to the southeast. Mean annual precipitation for this area was 7.82 cm, primarily occurring from January to March and again from August to September. Climate is typical of the Colorado Desert; mean annual temperature was 23°C, December is the coldest month (5°–19° C), and July the hottest month (27°–43° C) (Adams and Comrie 1997, Higgins et al. 2004, Western Regional Climate Center 2014). Seventy-one percent of the study area is federally owned, and the remaining is either

state or privately owned. The dominant vegetation communities within the study area were Sonoran creosote bush scrub (*Larrea tridentata*) and dry desert wash woodland (Holland 1986). Sonoran creosote bush scrub is a widely-spaced shrub community occurring on well-drained secondary soils of fans, slopes, and valleys (Holland 1986). Creosote bush and white bursage (*Ambrosia dumosa*) are the dominant shrub species in this plant community (Holland 1986). Dry desert wash woodland and dense microphyllous thorn scrub woodland also are found in sandy or gravelly washes and arroyos (Holland 1986). Palo verde (*Cercidium flordium*), desert willow (*Chilopsis linearis*), and desert ironwood (*Olneya tesota*) are the dominant plants in these communities (Holland 1986).

The Bureau of Land Management (BLM) is the primary landowner with 68% of lands in the study area under their management; with remaining lands under state, county, or private ownership. A 550-MW utility-scale solar energy facility, located on BLM lands, encompassing 14.97 km<sup>2</sup> was located in the north-central portion of the study area. Construction of the facility was initiated in September 2011 and was on-going during this study (Figure 3).

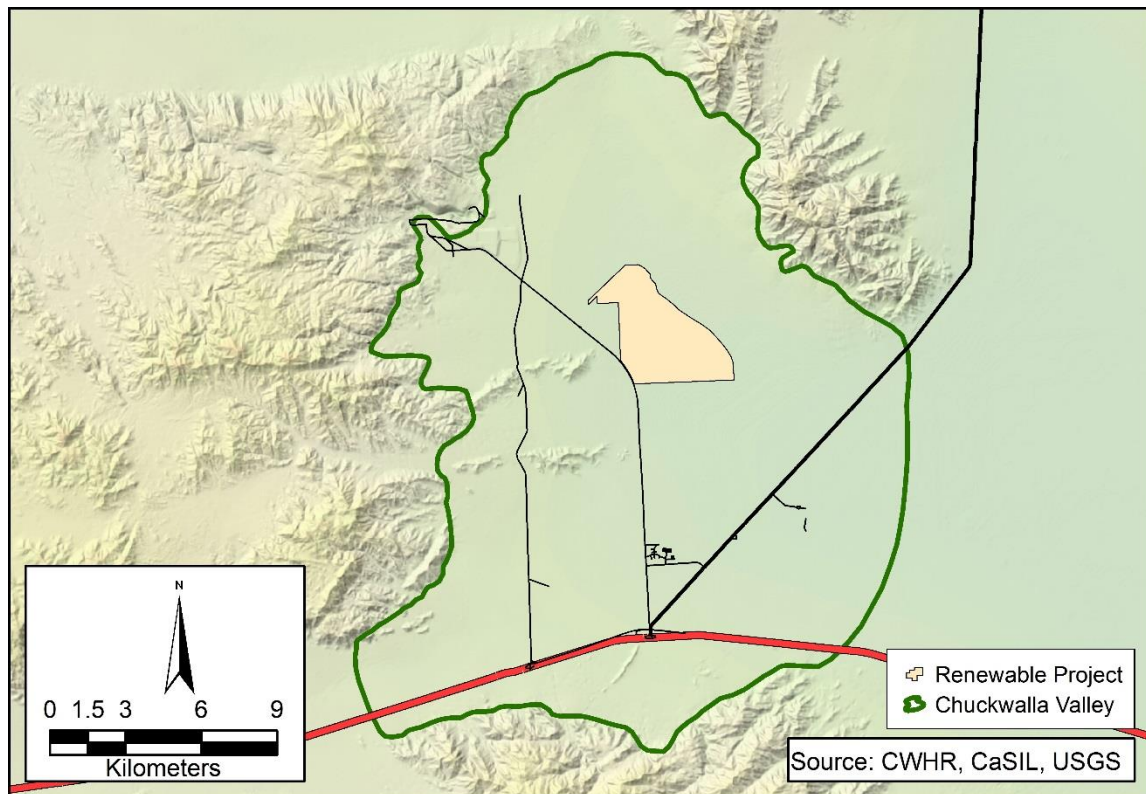


Figure 3. Upper Chuckwalla Valley, Riverside County, California.



## CHAPTER II

### HOME RANGE AND POPULATION DENSITY

As a result of increased interest in the development of alternative sources of energy, utility-scale renewable energy projects have increased over the past decade in California's southeastern desert regions. This is in part due to the State's Renewable Energy Portfolio Standard (RPS; Senate Bill 1038), which mandates a 33% contribution from renewable energy sources and increased federal assistance (e.g., grants and tax incentives) under the American Recovery and Reinvestment Act of 2009 (Pub. L. No. 111–5).

All utility-scale renewable energy projects have been subject to rigorous environmental review under the California Environmental Quality Act (CEQA) and/or the National Environmental Policy Act (NEPA) to assess potential environmental impacts resulting from project development. Subsequent to CEQA and/or NEPA, environmental reviews of critical ecological knowledge gaps (demographics, home range size, survival, etc.) for multiple species, including the desert kit fox, were identified. A 2-year radio-telemetry study was conducted to obtain regional baseline life history and ecological data of desert kit foxes in the Upper Chuckwalla Valley, Riverside County, California. These data were necessary to both inform decision makers and estimate potential environmental impacts of proposed anthropogenic development, including utility-scale solar, in California's southeastern deserts. Objectives for this study were to estimate: (1) seasonal and annual home range size (fixed kernel and minimum

convex polygon), (2) home range overlap, and (3) population densities of desert kit foxes adjacent to a utility-scale solar energy development.

## METHODS

### Capture and Marking

Wire mesh live traps (Tomahawk Live Traps, Hazelhurst, WI, USA) baited with meat scraps (e.g., bacon, chicken, and beef) were used to capture desert kit foxes from October 2012 to May 2014. Traps were active from 1/2 hour before sunset to within 1/2 hour of sunrise, with all traps checked and animals processed no later than 2-hours after sunrise. Desert kit foxes were removed from traps by coaxing captured individuals into a canvas bag (Cypher et al. 2009), where individuals were weighed and physically restrained to place a muzzle with eye cover prior to further processing. Each captured fox was sexed, fitted with an ear and PIT tagged, had a 2-mm tissue punch collected, and were fitted with mortality sensitive VHF radio collars (V5C 162C, Sirtrack, Havelock North, NZ). All capture and marking procedures were conducted in accordance with American Society of Mammologists guidelines for the use of wild animals in research (Sikes et al. 2011) and were approved by the California Department of Fish and Wildlife.

### Telemetry

Radio telemetry was used to locate individual desert kit foxes 5–7 nights per week (Millspaugh et al. 2012). A maximum likelihood estimator in the Location of A Signal (LOAS; Hegymagas, Hungary) software was used to determine nightly kit fox locations. Locations obtained via visual, homing, and telemetry were plotted in ArcGIS 10.1

(ESRI, Redlands, CA) and exported for further analyses in Geospatial Modeling Environment (GME; Beyer 2012).

### Seasonal and Annual Home Range

Based on kit fox reproductive biology, the year was divided into the following 3 biological periods: pup-rearing (March-July), dispersal (August-October), and pair formation (November-February). Seasonal periods were modified from those previously reported (Olson and Lindzey 2002, Kitchen et al. 1999, Zoellick et al. 1989) based on study specific observations. Annual and seasonal (e.g., pup-rearing, dispersal, and pair formation) kernel home range (95% fixed kernel) and core home range (50% fixed kernel) were calculated using GME (Beyer 2012). Additionally, annual and seasonal 100% minimum convex polygons (MCP) were calculated using GME (Beyer 2012). The use of multiple estimators of home range allowed for comparisons to previous studies in Arizona, California, Utah, and Mexico. I compared estimates annual and seasonal male and female home range (e.g., kernel home, kernel core, and MCP) with the use of a Mann-Whitney U-test in Minitab 16 (Minitab Inc., State College, PA). The Mann-Whitney U-test was selected to compare seasonal and annual home range estimates due to their non-normal distributions.

### Home Range Overlap

The 'isectpolypoly' function in GME (Beyer 2012) was used to determine 95% fixed kernel home range overlap for four dyad groupings: male-male, female-female, male-female unpaired, and male-female paired. The overlap for each individual within a dyad was averaged to obtain the mean home range overlap. I calculated mean and standard

error for each dyad group and tested for difference using a one-way analysis of variance (ANOVA).

### Population Densities

The number of radio collared desert kit foxes and capture/recapture data were used to estimate maximum number known alive each month (White and Ralls 1993, Ralls and White 1995). The monthly maximum known alive estimate was averaged and divided by the study area size (261 km<sup>2</sup>) to obtain a mean ( $\pm$  SE) desert kit fox density for the Upper Chuckwalla Valley, California.

### RESULTS

Seasonal and annual home ranges for individual kit foxes were calculated based on radio telemetry fixes (Appendix 1). The minimum number of radio-telemetry fixes used to estimate seasonal home range was 25 with a minimum of 75 fixes used to estimate annual home ranges. A total of 9,837 radio-telemetry fixes were collected between October 2012 and August 2014 on 56 radio-collared desert kit foxes (Figure 4).

#### Annual and Seasonal Kernel Home Range

There was no statistically significant difference between male and female annual kernel home ( $P = 0.682$ ) or core range ( $P = 0.381$ ) in 2012–2013. Due to no difference between male and female annual kernel home and core range, data for the sexes were combined and an estimated annual home range of  $15.77 \pm 1.03$  km<sup>2</sup> with a core range of  $3.53 \pm 0.28$  km<sup>2</sup> was determined (Table 1). Similarly there was no statistically significant difference between male and female 10-month kernel home ( $P = 0.894$ ) and core range ( $P = 1.000$ ) in 2013–2014. Therefore, data for the sexes were combined and

an estimated 10-month kernel home range of  $12.15 \pm 1.47 \text{ km}^2$  with a core range of  $2.60 \pm 0.27 \text{ km}^2$  was determined (Table 2).

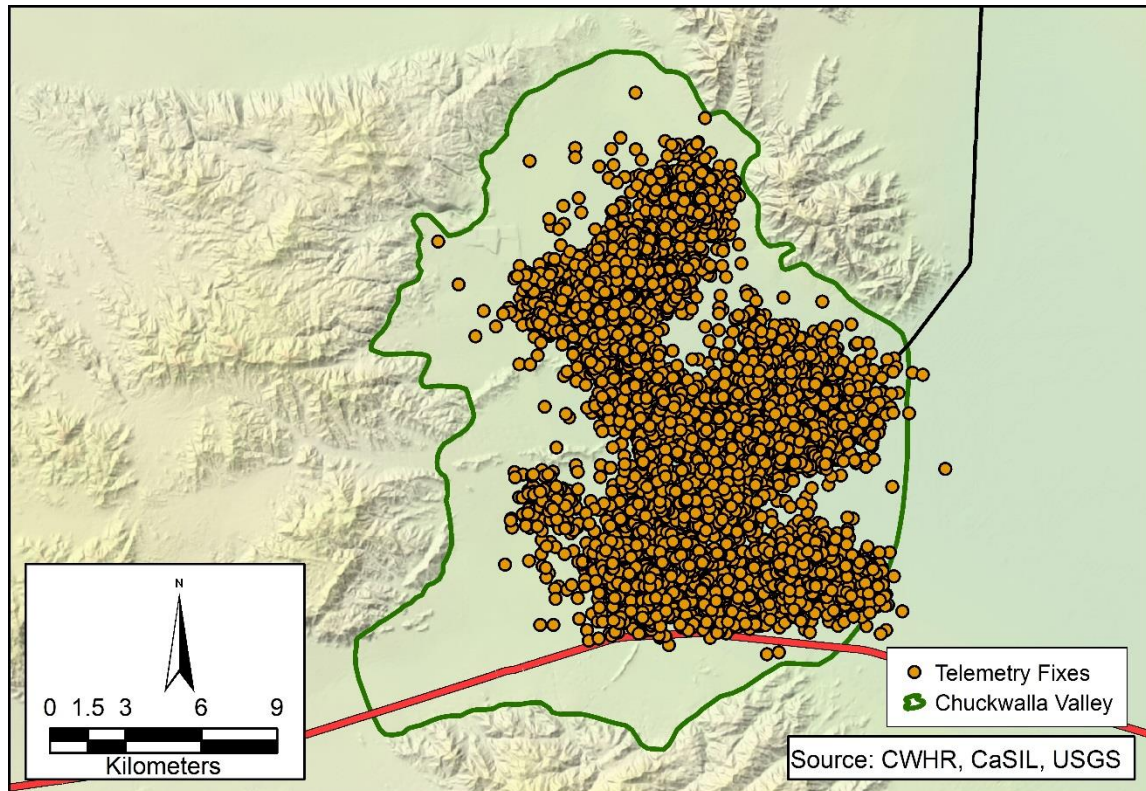


Figure 4. Desert kit fox radio-telemetry fixes October 2012-August 2014.

There was no statistically significant difference between male and female pair formation kernel home ( $P = 0.593$ ) or core ( $P = 0.343$ ) range 2012–2013 (Table 1). Similarly there was no statistically significant difference between male and female pair formation kernel home ( $P = 0.704$ ) or core ( $P = 0.842$ ) range in 2013–2014 (Table 2). Due to a lack of difference in pair formation kernel home range, data for the sexes for

each period were combined and an estimated pair formation kernel home range of  $14.31 \pm 1.35 \text{ km}^2$  in 2012–2013 and  $11.24 \pm 1.24 \text{ km}^2$  in 2013–2014 was determined.

Similarly, male and female pair formation kernel core range by year were combined and an estimated kernel core range of  $3.20 \pm 0.33 \text{ km}^2$  in 2012–2013 and  $2.52 \pm 0.29 \text{ km}^2$  in 2013–2014 was determined. The differences between years for both kernel home and core range during pair formation also were determined. Pair formation kernel home range was greater ( $P = 0.032$ ) in 2012–2013 than 2013–2014, with no statistically significant difference ( $P = 0.094$ ) in pair formation kernel core range size between years. There was no statistically significant difference between male and female pup-rearing kernel home ( $P = 0.577$ ) or core ( $P = 0.760$ ) range in 2013 (Table 1). Similarly there was no statistically significant difference between male and female pup-rearing kernel home ( $P = 0.381$ ) or core ( $P = 0.713$ ) range in 2014 (Table 2). Male and female pup-rearing kernel home range and core range by year were combined to and a pup-rearing kernel home range of  $14.23 \pm 1.29 \text{ km}^2$  in 2013 and  $10.96 \pm 1.19 \text{ km}^2$  in 2014 were determined. The combined pup-rearing kernel core range was  $3.26 \pm 0.30 \text{ km}^2$  in 2013 and  $3.51 \pm 0.82 \text{ km}^2$  in 2014. There was no statistically significant difference between years for pup-rearing kernel home ( $P = 0.081$ ) or core ( $P = 0.447$ ) range.

There was no statistically significant difference between male and female dispersal kernel home ( $P = 0.341$ ) or core ( $P = 0.683$ ) range in 2013. Due to a lack of statistical difference the sexes were combined and an estimated dispersal kernel home range of  $14.61 \pm 1.11 \text{ km}^2$  with a core range of  $3.35 \pm 0.25 \text{ km}^2$  for 2013 was determined (Table

1). Dispersal kernel home or core range size in either 2012 or 2014 could not be determined due to incomplete seasonal sampling.

#### Annual and Seasonal MCPs

There was no statistically significant difference between male and female annual MCP home range in 2012–2013 ( $P = 0.820$ ). Due to no difference between sexes in annual MCP home range, the sexes were combined and an estimated mean annual MCP home range of  $18.48 \pm 1.77 \text{ km}^2$  was determined (Table 3). Additionally there was no statistically significant difference between male and female 10-month MCP home range in 2013–2014 ( $P = 0.788$ ). With no difference detected between the sexes, the sexes were combined and an estimated mean 10-month MCP home range of  $13.96 \pm 1.97 \text{ km}^2$  was determined (Table 3).

There was no statistically significant difference between male and female pair formation MCP home range in 2012–2013 ( $P = 0.855$ ) or in 2013–2014 ( $P = 0.910$ ). The sexes for each pair formation period were combined and no statistically significant difference between 2012–2013 ( $12.72 \pm 1.64 \text{ km}^2$ ) and 2013–2014 were found ( $8.15 \pm 0.96 \text{ km}^2$ ) ( $P = 0.111$ , Table 3). Mean pair formation MCP home range across years was  $9.29 \pm 0.77 \text{ km}^2$ . There was no statistically significant difference between male and female pup-rearing MCP home range in 2013 ( $P = 0.109$ ) or in 2014 ( $P = 0.437$ ). Therefore, the sexes for each pup-rearing period were combined and no statistically significant were found between 2013 ( $12.72 \pm 1.64 \text{ km}^2$ ) and 2014 ( $9.77 \pm 1.01 \text{ km}^2$ ) ( $P = 0.205$ , Table 3). Mean pup-rearing home range across years was  $11.18 \pm 0.96 \text{ km}^2$ . There was no statistically significant ( $P = 0.180$ ) difference between male and female

dispersal MCP home range in 2012–2013. The sexes were combined resulting in a dispersal MCP home range of  $9.30 \pm 1.40 \text{ km}^2$ .



Table 1. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual kernel core (50%) and home range (95%) estimates ( $\bar{x} \pm SE$ ; km<sup>2</sup>), 2012–2013, southeastern California.

	2012-2013					
	50%			95%		
	M	F	All	M	F	All
Pair Formation	3.65 ± 0.60	2.81 ± 0.31	3.20 ± 0.33	15.60 ± 2.44	13.17 ± 1.36	14.31 ± 1.35
Pup-Rearing	3.61 ± 0.46	3.29 ± 0.42	3.26 ± 0.30	13.25 ± 1.59	15.15 ± 2.02	14.23 ± 1.29
Dispersal	3.26 ± 0.41	3.45 ± 0.29	3.35 ± 0.25	13.16 ± 1.51	16.18 ± 1.58	14.61 ± 1.11
Annual	3.66 ± 0.40	3.40 ± 0.39	3.53 ± 0.28	15.91 ± 1.52	15.63 ± 1.44	15.77 ± 1.03

Table 2. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and 10-month kernel core (50%) and home range (95%) estimates ( $\bar{x} \pm SE$ ; km<sup>2</sup>), 2013–2014, southeastern California.

	2013-2014					
	50%			95%		
	M	F	All	M	F	All
Pair Formation	2.33 ± 0.23	2.68 ± 0.51	2.52 ± 0.29	11.27 ± 1.36	11.20 ± 2.01	11.24 ± 1.24
Pup-Rearing	2.89 ± 0.51	4.04 ± 1.48	3.51 ± 0.82	11.02 ± 2.37	10.90 ± 0.95	10.96 ± 1.19
Dispersal	-	-	-	-	-	-
Annual	2.74 ± 0.49	2.49 ± 0.28	2.60 ± 0.27	13.51 ± 3.06	11.09 ± 1.14	12.15 ± 1.47

Table 3. Kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual 100% MCP home range estimates ( $\bar{x} \pm SE$ ; km<sup>2</sup>), 2012–2014, southeastern California.

	<b>2012-2013</b>			<b>2013-2014</b>		
	<b>M</b>	<b>F</b>	<b>All</b>	<b>M</b>	<b>F</b>	<b>All</b>
Pair Formation	10.06 ± 1.57	10.96 ± 1.83	10.52 ± 1.20	8.84 ± 1.72	7.52 ± 0.99	8.15 ± 0.96
Pup-Rearing	9.56 ± 1.20	15.69 ± 2.82	12.72 ± 1.64	9.72 ± 1.84	9.81 ± 1.05	9.77 ± 1.01
Dispersal	6.55 ± 0.96	11.28 ± 2.22	9.30 ± 1.40	-	-	-
Annual	16.84 ± 1.82	20.04 ± 2.99	18.48 ± 1.77	15.95 ± 5.01*	12.86 ± 1.45*	13.96 ± 1.97*

\*indicates 10 month estimate

### Home Range Overlap and Population Density

No statistically significant difference ( $F_{3,1333} = 0.70$ ,  $P = 0.554$ ) was found in home range overlap within groups between seasons. There was a statistically significant overlap ( $F_{3,152} = 31.32$ ,  $P < 0.0001$ ) effect of group on annual home range. A 2-sample t-test indicated mean home range overlap for mated pairs ( $\bar{X} = 79.3\%$ ,  $SD = 5.58$ ) was significantly different ( $t_{38} = -34.59$ ,  $P < 0.0001$ ) than unmated pairs ( $\bar{X} = 20.9\%$ ,  $SD = 19.4$ ; Figure 5).

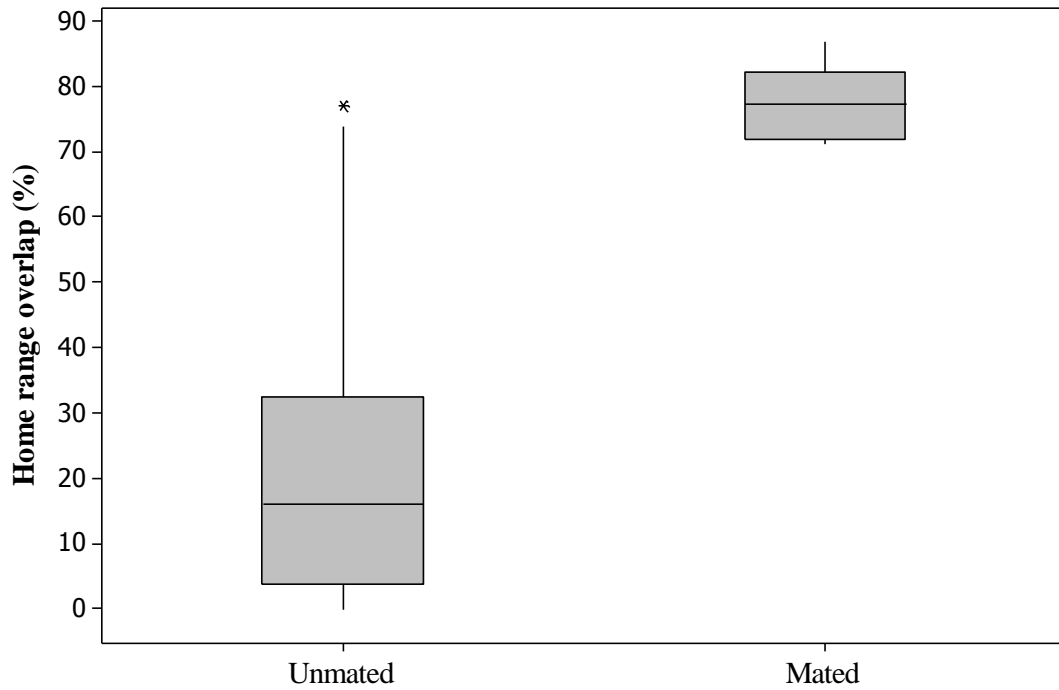


Figure 5. Percent 95% fixed kernel annual home range overlap for unmated and mated.

The mean minimum known alive during this study was 47 (range 33–71) resulting in an estimated desert kit fox density of  $0.18 \pm 0.05/\text{km}^2$  (range 0.13–0.27/ $\text{km}^2$ ). The estimated desert kit fox density varied over time (Figure 6), this variation is attributable to differential trapping/re-trapping efforts, specifically during the pupping season and decreased re-collar efforts in 2014.

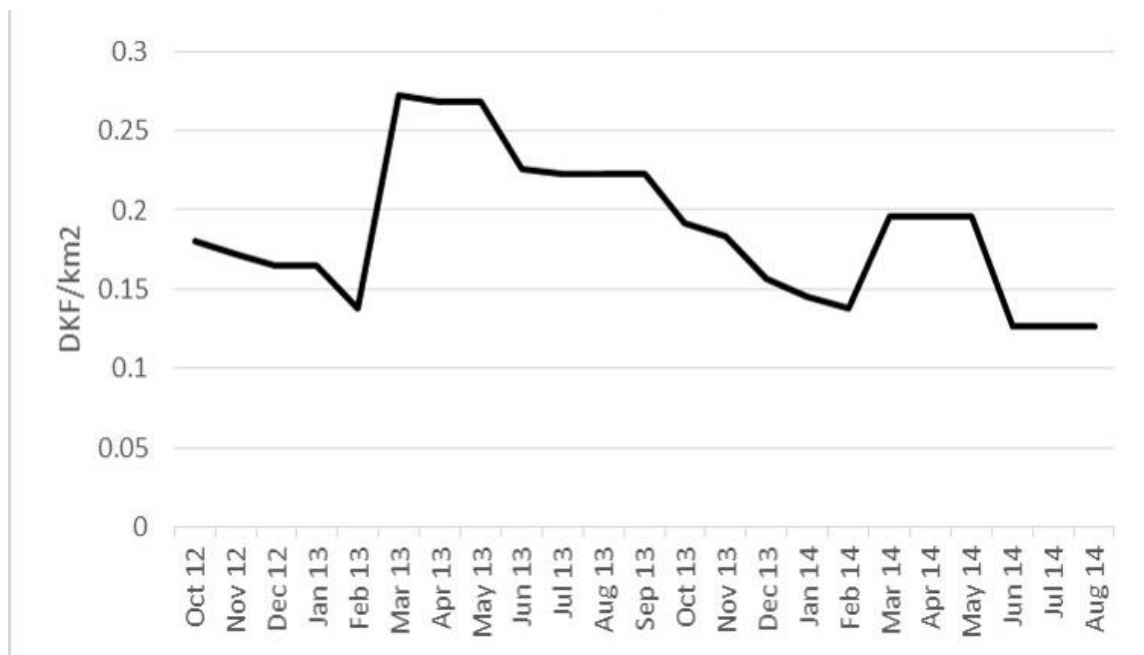


Figure 6. Desert kit fox population density estimate over time.

## DISCUSSION

List and Macdonald (2003) cautioned comparing results between home range studies due to the influence of the estimator of choice (e.g., kernel or MCP). To facilitate comparison and more accurately represent the study results, the annual and seasonal

home ranges using both 100% MCP and 95% fixed kernel, as well as core range using the 50% fixed kernel were calculated desert kit fox pairs, Upper Chuckwalla Valley, California (2012–2014).

Annual male MCP home range size during this study was similar to those reported in western Arizona ( $16.8 \pm 2.6 \text{ km}^2$ ; Zoellick and Smith 1992) and 4.9 times larger than those reported in Utah ( $3.4 \text{ km}^2$ ; O'Neal et al. 1987). Annual female MCP home range size during this study was 1.9 times larger than western Arizona ( $10.7 \pm 1.2 \text{ km}^2$ ; Zoellick and Smith (1992) and 6.67 times larger than Utah ( $3.0 \text{ km}^2$ ; O'Neal et al. 1987). The mean combined annual MCP home range during this study was 1.3 times larger than western Arizona ( $14.2 \pm 1.92 \text{ km}^2$ ; Zoellick and Smith 1992), 1.6 times larger than Carrizo Plains National Monument ( $11.6 \pm 0.9 \text{ km}^2$ ; White and Ralls 1993), 1.7 times larger than Mexico ( $11.0 \pm 4.6 \text{ km}^2$ ; List and Macdonald 2003), 4.3 times larger than the Naval Petroleum Reserve in California ( $4.34 \pm 1.43 \text{ km}^2$ ; Cypher et al. 2001), and 4.95 times larger than the Barry M. Goldwater Air Force Range, Arizona ( $3.73 \pm 0.28 \text{ km}^2$ ; Bowles et al. 1995).

Mean annual kernel home range size during this study was  $15.91 \pm 1.52 \text{ km}^2$  for males,  $15.63 \pm 1.44 \text{ km}^2$  for females, and  $15.77 \pm 1.03 \text{ km}^2$  when combined (Table 1). Kernel home range size during this study was 1.3 times larger than from Mexico ( $11.5 \pm 4.1 \text{ km}^2$ ; List and Macdonald 2003), 63% larger than Lokern Natural Area, California ( $5.91 \pm 0.44 \text{ km}^2$ ; Nelson et al. 2007). Conversely, kernel home range size during this study was 23.1% smaller than kernel home ranges from Utah from 2010–2012 ( $20.5 \text{ km}^2$ ; Dempsey et al. 2014).

Seasonal kernel home range sizes during this study were smaller than those estimated by Dempsey et al. (2014). The decreased seasonal home range size observed during for these 2 studies was likely due to different seasonal lengths used in each study.

Mean desert kit fox annual core range size during this study was  $3.66 \pm 0.40 \text{ km}^2$  for males,  $3.40 \pm 0.39 \text{ km}^2$  for females, and  $3.53 \pm 0.28 \text{ km}^2$  when combined (Table 1). Annual desert kit fox core range sizes have not been previously reported and therefore not comparable to previous studies.

This study, as well as, the studies conducted by Bowles et al. (1995) and Zoellick and Smith (1992) were conducted in the Lower Colorado River Valley subdivision of the Sonoran Desert province. Interestingly, annual MCP home range sizes from Zoellick and Smith (1992) and Bowles et al. (1995) represent the most and least similar, respectively, to this study's estimated annual MCP home range size. Annual MCP home range sizes intermediate to the two Arizona studies (Bowles et al. 1995, Zoellick and Smith 1992) were studies conducted in California's Central Valley (Cypher et al. 2001, White and Ralls 1993) and Mexico (List and Macdonald 2003), all of which were considered grassland communities. Differences in vegetation community type may influence desert kit fox annual home range size as evidences by similarities between this study and Zoellick and Smith (1992).

Another potentially influencing factor in differences between annual and seasonal home range estimates from this study and previously reported studies is environmental conditions, specifically deviation from normal precipitation. Severe to extreme drought conditions were present during this study (National Climate Data Center 2014). With the

exception of research conducted on the Carrizo Plains National Monument from 1988–1990 (White and Ralls 1993), precipitation was at or above average for all previous kit fox research based on historic Palmer Drought Severity Indices (National Climate Data Center 2014). Lacking more discrete precipitation data from previous research studies the influence of drought conditions cannot be directly quantified.

### Home Range Overlap

Annual mated pair home range overlaps during this study (79.3%) were higher than previously reported for western Arizona (75%; Zoellick and Smith 1992), California (70%; White and Ralls 1993) and Utah (74.2%; Daneke et al. 1984). A similar pattern was found for unmated dyad groups with home range overlaps during this study (20.9%) being higher than both western Arizona (12%; Zoellick and Smith 1992), California (13.7%; White and Ralls 1993), and Utah (Daneke et al. 1984) where no overlap was found between neighboring unmated pairs.

While the results of this study appear to confirm previous findings for annual home range overlap between mated pairs, the overlap between neighboring unmated individuals was twice previously reported. The higher degree of annual home range overlaps between unmated dyads during this study may be related to a larger number of individuals radio-collared and monitored during this study. Small sample sizes, particularly of unpaired individuals in previous research likely influenced the degree of observed annual home range overlap.



### Population Density

Desert kit fox densities in the Upper Chuckwalla Valley, California, were estimated as  $0.18 \pm 0.05/\text{km}^2$ . Density estimates during this study were similar to densities at the Carrizo Plain, California (0.19) from 1989–1992 (White and Ralls 1993), Dugway Proving Ground, Utah (0.17) from 1966–1969 (Egoscue 1975), and the Desert Ecology Range, Utah (0.16) from 1983 (O'Neal et al. 1987). White and Garrott (1997) summarized 8 kit fox study sites from 1955 to 1996 across the range, which ranged from 0.14–1.57/ $\text{km}^2$ .

## CHAPTER III

### REPRODUCTIVE SUCCESS, RATE, AND MEAN LITTER SIZE

Reproductive parameters (e.g., reproductive success, mean litter size, and reproductive rates) of the federally endangered and California threatened San Joaquin kit fox are well known; with high annual and geographic variation (White and Ralls 1993, Cypher et al. 2000). By comparison, little is known about reproductive parameters for kit foxes outside the range of the San Joaquin kit fox in California. Since 1977, four studies have been conducted on desert kit foxes in California, with only O'Farrell and Gilbertson (1986) reporting reproductive values. The three remaining studies focused on the effects of road (Clevenger et al. 2010), field metabolic rate and daily movements (Girard 2001), and disease prevalence (Miller et al. 2000) of the desert kit fox.

Regional knowledge gaps for basic life history parameters in California's desert kit fox populations limit the ability of both resource managers and policy makers to accurately manage and assess potential impacts to these populations. To address and fill these knowledge gaps, a 2-year study was conducted to determine the following: (1) reproductive success (whelping females/total females), (2) mean litter size, and (3) reproductive rate (pups/whelping female).

## METHODS

### Capture and Marking

Wire mesh live traps (Tomahawk Equipment Company, Tomahawk, WI, USA) baited with meat scraps were used to capture desert kit foxes. Fifty-six adult and juvenile kit foxes were fitted with mortality-sensitive radio collars between October 2012 and

December 2013, these collared individuals were located 5–7 nights per week (Millspaugh et al. 2012). Additionally, desert kit fox pups at natal den complexes in May 2013 and 2014 were captured. Each pup was weighed, aged, sexed and all captured individuals were fitted with ear and Passive Integrated Transponder tags for identification. All capture and marking procedures were conducted in accordance with American Society of Mammologists guidelines for the use of wild animals in research (Sikes et al. 2011) and all activities were approved by the California Department of Fish and Wildlife.

### Reproduction

Using standard radio-telemetry techniques, collared female desert kit foxes were monitored during the 2013 and 2014 breeding seasons (Millspaugh et al. 2012). Potential natal den complexes were located from late January to early February, and each location was determined using a handheld GPS unit. Both direct and indirect observations (e.g., game camera) were used at each complex to determine if pups were present. Female desert kit foxes were considered to have successfully reproduced if  $\geq 1$  pup was observed at the den site, and female reproductive success rates were determined by dividing successfully reproducing females by the number of all females monitored in a season. Litter size was determined by direct (e.g., observation and/or trapping) and indirect observation (e.g., maximum # of pups photographed at a den) from March to July, an annual mean ( $\pm SE$ ) litter size was calculated, and mean litter size between years was compared using a 2-sample *t*-test. Annual reproductive rates were calculated by

multiplying reproductive success and mean litter size (White and Garrott 1997) and tested for differences using a  $\chi^2$  test.

## RESULTS

Sixteen female desert kit foxes were monitored during each breeding season and information, including location, was recorded at all potential natal den complexes in 2013 and 2014 (Figure 7). Fifty percent of female desert kit foxes successfully reproduced in both 2013 and 2014. Three successfully reproducing desert kit fox females from 2013 successfully reproduced in 2014, with no reuse of previous natal den sites. Distances from the 2013 to 2014 natal den sites ranged from 5.7–16.5 km<sup>2</sup>. There was no statistically significant difference ( $t_{44} = 1.2$ ,  $P = 0.225$ ) of mean distance between natal dens in 2013 ( $6.84 \pm 0.64$  km<sup>2</sup>) and 2014 ( $8.28 \pm 9.82$  km<sup>2</sup>), nor was there a statistically significant difference ( $U = 323$ ,  $P = 0.179$ ) between 2013 ( $M = 6.93$  km<sup>2</sup>) and 2014 ( $6.41$  km<sup>2</sup>).

The mean litter size during this study was  $2.69 \pm 0.30$  ( $SE$ , range 1–6), with no statistically significant difference ( $t_9 = 0.2$ ,  $P = 0.844$ ) between 2013 ( $2.75 \pm 0.25$  [ $SE$ ]; range 2–4) and 2014 ( $2.63 \pm 0.56$  [ $SE$ ]; range 1–6). The mean reproductive rate for the entire study was 1.35 with no statistically significant ( $\chi^2 = 0.001$ ,  $P = 0.97$ ) difference between reproductive rates in 2013 (1.38) and 2014 (1.32) (Table 4).

Table 4. Female desert kit foxes monitored (*n*), reproductive success, mean litter size, litter size range, and reproductive rate, Upper Chuckwalla Valley, California (2013–2014).

Year	<i>n</i>	Reproductive Success	Mean Litter	Litter Size Range	Reproductive Rate
2013	16	0.5	$2.75 \pm 0.25$	2–4	1.38
2014	16	0.5	$2.63 \pm 0.56$	1–6	1.32
Total	32	0.5	$2.69 \pm 0.30$	1–6	1.35

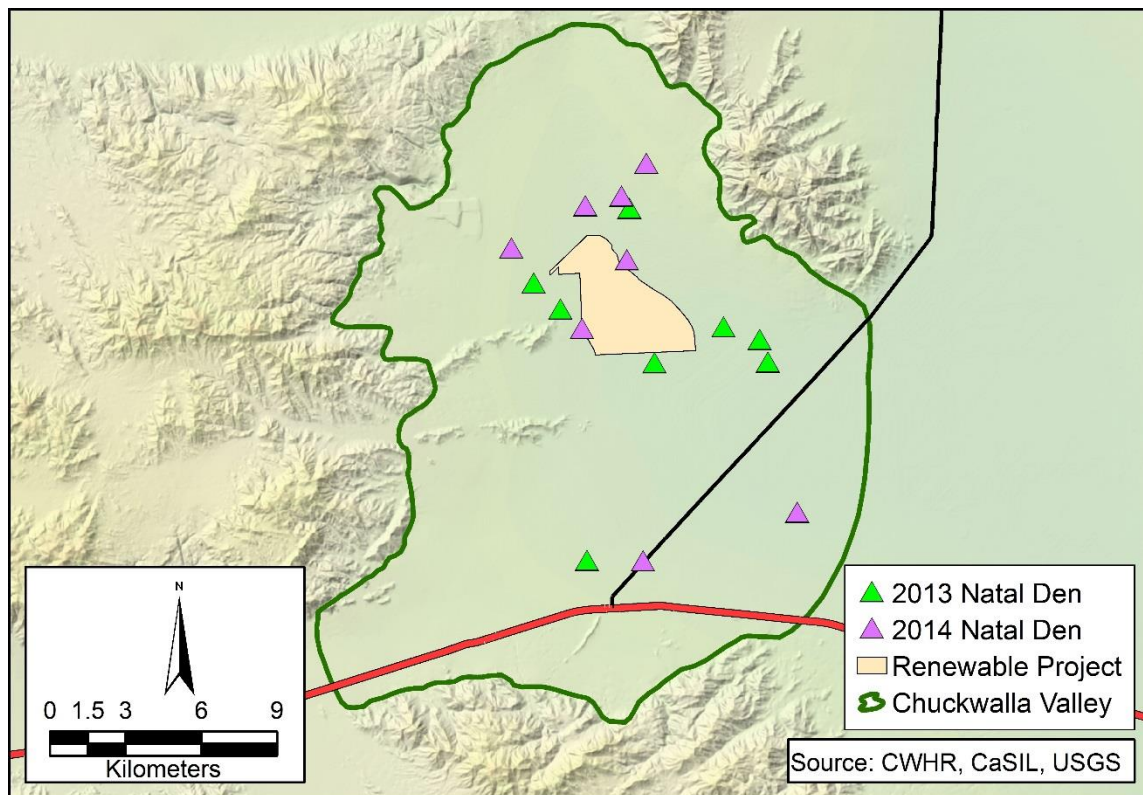


Figure 7. Desert kit fox natal den locations – 2013 and 2014.

## DISCUSSION

Fifty percent of female desert kit foxes successfully reproduced in two breeding seasons during this study. The annual reproductive success rate during this study was the same as rates reported for 1977–1979 in the Mojave Desert, California (50%, O'Farrell and Gilbertson 1986) and within the range of annual reproductive success rates (20–100%) for the Naval Petroleum Reserves in California from 1980–1995 (Cypher et al. 2000). Desert kit fox reproductive success rate for this study (50%) was higher than rates reported on the Carrizo Plain (21%) from 1989–1991 (White and Ralls 1993), but below the Naval Petroleum Reserves in California (61.1%) from 1980–1985.

Mean litter size for the entire study was  $2.69 \pm 0.30$  (*SE*) pups/female and within the mean litter size range for four discrete periods at the Dugway Proving Grounds, Utah (1.94–2.31; Arjo et al. 2007). Conversely, mean litter size during this study was lower than the 15-year average (3.8, range 2.0–4.8) reported for the Naval Petroleum Reserves in California (Cypher et al. 2000)

Reproductive rates during this study (1.32–1.38) were within the previously reported range wide reproductive rates (0.5–4.6) compiled by Ralls and White (1997). Results for this study were lower than all reported reproductive rates with the exception of the Carrizo Plain, California from 1989–1992 (0.5, Ralls and White 1995) and Camp Roberts, California from 1989–1991 (1.0, Standley et al. 1992). When compared to the Naval Petroleum Reserves in California, reproductive rate of desert kit foxes in the Upper Chuckwalla Valley were lower than all but 3 years: 1990, 1991, and 1995 (Cypher et al. 2000).

Prey availability and drought can influence kit fox reproductive success and litter size (White and Ralls 1993, White et al. 1996, White and Garrott 1997). Reproductive rates also may be influenced by prey availability and drought. Leporid abundance has been identified as a potential influencing factor in kit fox reproduction. White and Garrott (1997) summarized the results of 11 studies at 8 study sites from 1955–1996. Seven of the 11 studies identified reported both leporid abundance and reproductive rates with 13.7% (adj.  $R^2$ ) of the variation in reproductive rates explained by leporid abundance. These results suggest factors other than leporid abundance may be influencing kit fox reproductive rates. Small mammals are also known to be a primary kit fox food source (Cypher et al. 2001, McGrew 1979) and the densities of small mammals could potentially influence reproductive rates of kit foxes more strongly than leporid abundance.

Prey availability was not quantified during this study, and therefore, the potential affects prey resources on reproductive parameters could not be quantified. However, during the breeding season, drought conditions from severe to extreme in 2013 and extreme throughout 2014 breeding (National Climate Data Center 2014). Drought conditions during this study may have influenced reproductive parameters by reducing small mammal prey availability (Dennis and Otten 2000) and increasing water stress (Golightly and Ohmart 1983, Girard 2001). Combined, these factors may have resulted in underestimated reproductive success if pups whelped, but did not emerge from the natal den.

## CHAPTER IV

### SURVIVAL AND CAUSE SPECIFIC MORTALITY

The southwestern United States has the highest potential for solar energy generation in the United States (Lopez et al. 2012), a region encompasses a majority of the desert kit fox's range (McGrew 1979; Figure 8). High solar energy generation potential coupled with federal assistance under the American Recovery and Reinvestment Act of 2009 (Pub L. 111–5), federal energy policy goals as stated in the Energy Policy Act of 2005 (Pub L. 109–58), and California's Renewable Energy Portfolio Standard goals (California SB X1–2) have led to increased solar production in California's southeastern desert region. Solar energy contributions to California's electrical grid have increased by 613% from 0.3% in 2004 to 1.82% in 2014 (California Energy Almanac 2014, U.S. Department of Energy 2014).

In California, the life history and ecology of San Joaquin kit foxes (*V. m. mutica*) have been extensively studied (Disney and Spiegel 1992, White and Ralls 1993, Cypher et al. 2000, Nelson et al. 2007, Cypher et al. 2009), with only four desert kit fox studies in the desert regions of the state (O'Farrell and Gilbertson 1986, Miller et al. 2000, Girard 2001, Clevenger et al. 2010). While the four identified studies have contributed to our general knowledge of desert kit fox's life history and ecology in California's southeastern deserts, none of these studies estimated either survival or sources of mortality. Objectives for this study were to: (1) estimate seasonal and annual survival and (2) determine cause-specific mortality sources for desert kit foxes in the Upper Chuckwalla Valley, Riverside County, California.



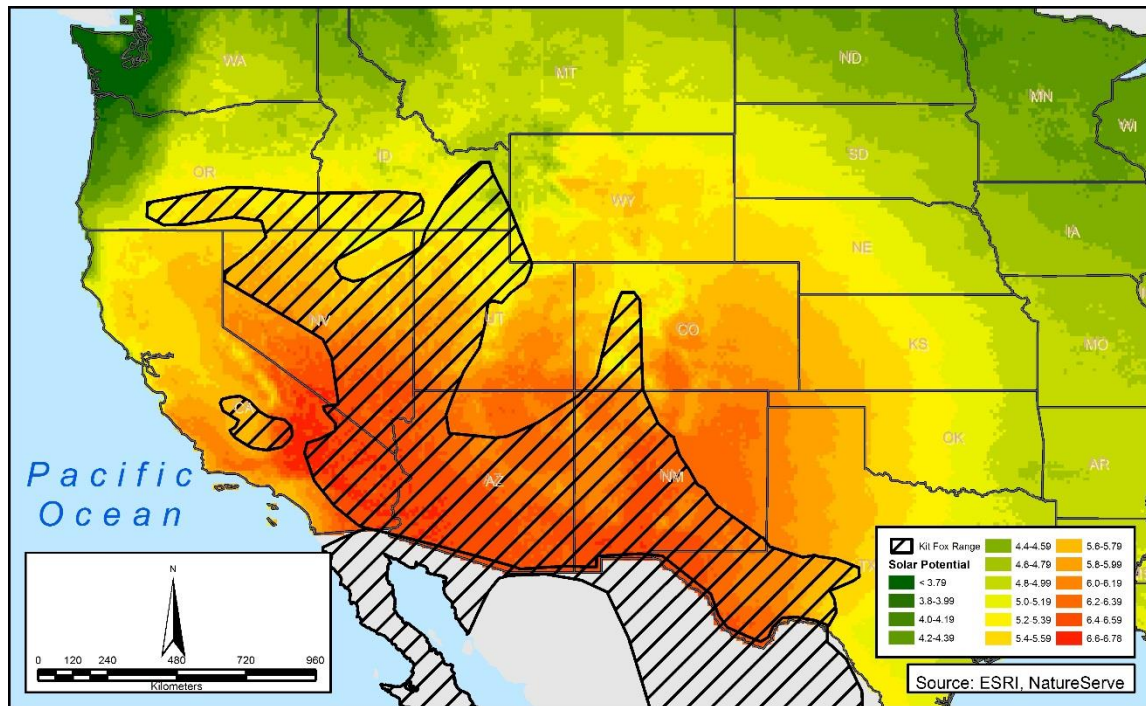


Figure 8. U.S. solar energy generation potential within the kit foxes distribution.

## METHODS

### Capture and Marking

Desert kit foxes were captured using wire mesh box style live traps (Tomahawk Equipment Company, Tomahawk, WI, USA). Traps were covered with burlap to reduce trap visibility and decrease potential stress (Cypher et al. 2009). Rope chew toys were fitted internally to each trap to prevent jaw injuries and provide stress reduction. Captured desert kit foxes were coaxed from the trap into a large canvas sack to facilitate securing each individual and processing (Cypher et al. 2009). Processing consisted of taking weights, fitting a muzzle with eye cover, aging, sexing, PIT tag implantation, ear tagging, and fitting mortality sensitive VHF radio collars (V5C 162C, Sirtrack, Havelock

North, NZ). Radio-collared desert kit foxes were tracked via standard radio-telemetry techniques nightly (Millspaugh et al. 2012). All capture, handling, and marking methods were developed and conducted in accordance with standards established by the American Society of Mammalogists (Sikes et al. 2011) and approved by the California Department of Fish and Wildlife.

### Survival Estimation and Analysis

Seasonal and annual survival rates of desert kit foxes were calculated in R (R Core Team 2013), using the staggered entry Kaplan-Meier estimator allowing for censoring due to radio failure, emigration, and multiple study entry periods (Pollock et al. 1989, Winterstein et al. 2001). Three seasonal survival periods: dispersal (August-October), pair formation (November-February), and pup-rearing (March-July) were based on previous studies (Zoellick et al. 1989, Kitchen et al. 2002, Olson and Lindzey 2002) and modified in accordance with observations made in this study. I used a log-rank test ( $\alpha = 0.05$ ) to compare male and female desert kit fox annual, seasonal, and study survival rates. A log-rank test also was used to compare seasonal survival rates between years based on sex.

### Mortality Determination

Cause specific mortality was determined using methods described by Disney and Spiegel (1992). Each mortality site was examined for the predator specific sign including tracks, scat, and hair as well as carcass disposition (e.g., buried or not buried). Carcasses were examined for puncture wounds and distance between puncture wounds (Ralls and White 1995).

## RESULTS

### Survival

There was no statistically significant ( $\chi^2_1 = 0.03$ ,  $P = 0.862$ ) difference between male (0.752) and female (0.885) annual survival rates. Male and female annual survival estimates were pooled resulting in an annual survival rate of 0.809 for 2012–2013. Similarly there was no statistically significant ( $\chi^2_1 = 0.03$ ,  $P = 0.875$ ) difference between male (0.892) and female (0.772) 11-month survival rates for 2013–2014. Male and female 11-month survival estimates were pooled resulting in an 11-month survival rate of 0.833. Additionally, there was no statistically significant difference ( $\chi^2_1 = 0.02$ ,  $P = 0.887$ ) between the male (0.670) and female (0.683) study survival rate (23-months). The pooled 2012–2013 annual survival rate during this study was 0.809, with a pooled 2013–2014 11-month survival rate of 0.833. The pooled study survival rate (23-months) was 0.674 (Table 5).

There was no statistically significant difference between male and female survival rates during pair formation in either 2012–2013 ( $\chi^2_1 = 0.08$ ,  $P = 0.929$ ) or 2013–2014 ( $\chi^2_1 = 0.02$ ,  $P = 0.929$ ). Similarly there was no statistically significant difference between male and female survival rates during pup-rearing in either 2013 ( $\chi^2_1 = 1.00$ ,  $P = 0.317$ ) or 2014 ( $\chi^2_1 = 0.78$ ,  $P = 0.378$ ). There was no statistically significant difference in male survival rates between years for the pair formation ( $\chi^2_1 = 0.00$ ,  $P = 0.964$ ) or pup-rearing ( $\chi^2_1 = 0.76$ ,  $P = 0.382$ ) seasons. Similarly, there was no statistically significant difference in female survival rates between years for the pair formation ( $\chi^2_1 = 0.10$ ,  $P = 0.755$ ) or pup-rearing ( $\chi^2_1 = 1.00$ ,  $P = 0.317$ ) seasons (Table 5).

Table 5. Survival estimates of radio collared desert kit foxes in southeastern California, 2012–2014.

	2012–2013			2013–2014		
	M	F	Combined	M	F	Combined
Pair Formation	0.868	0.885	0.876	0.891	0.836	0.864
Pup-rearing	0.944	1.000	0.969	1.000	0.923	0.964
Dispersal	1.000	1.000	1.000	-	-	-
Annual	0.752	0.885	0.809	0.892*	0.772*	0.833*

\*11-month estimate

#### Cause Specific Mortality

Eighty percent (12 of 15) of mortality sources were identified during this study.

Predation was the primary cause of 92% (11 of 12) of known mortalities. Coyote predation accounted for 64% (7 of 11) of all predations, with the remainder of predation caused by bobcat (*Lynx rufus*). Road kill accounted for 8% (1 of 13) of known fate mortalities (Figure 9).

During this study 73.3% (11 of 15) of all mortalities occurred during pair formation (Nov-Feb) with 20% (3 of 15) of all mortalities occurring during pup rearing (Mar-Jul). Predation exhibited a similar pattern with 71% (5 of 7) of coyote predations and 75% (3 of 4) of bobcat predations occurring during pair formation and 29% (2 of 7) of coyote predations occurring during pup rearing.

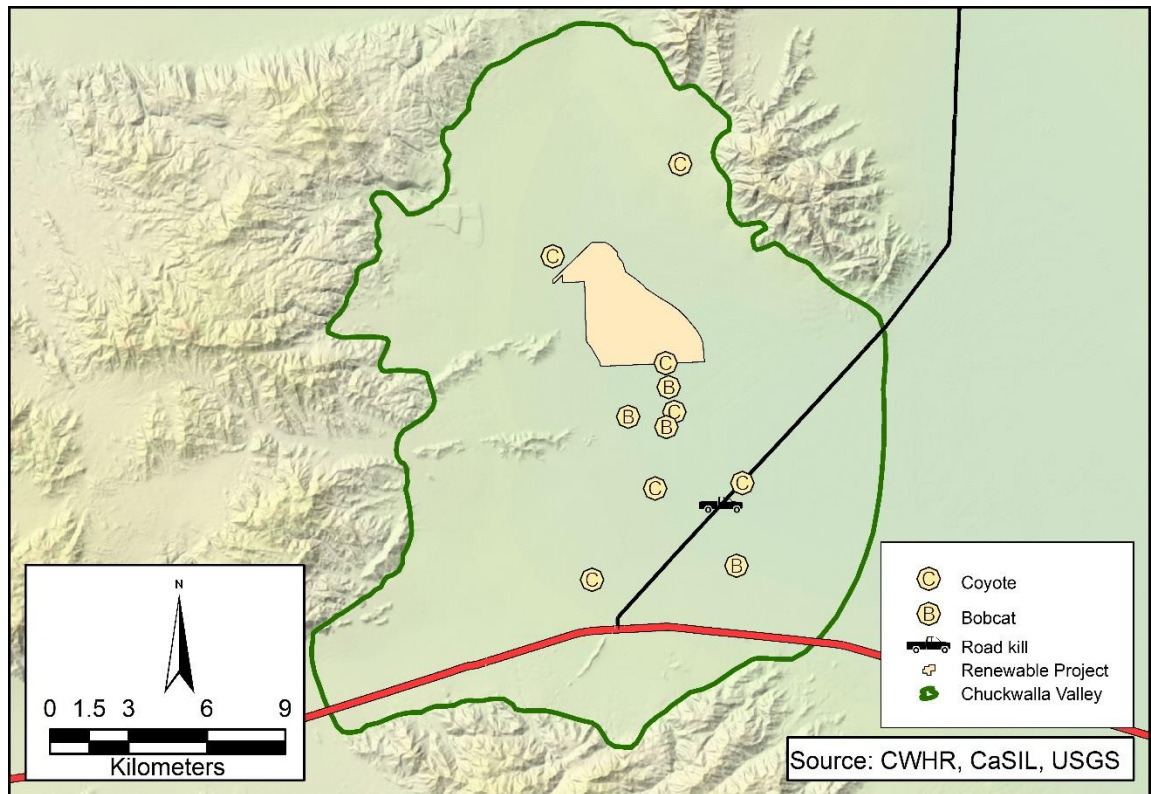


Figure 9. Desert kit fox predation location.

## DISCUSSION

Coyote predation was the primary source of kit fox mortality during this study and by extension the primary factor affecting kit fox survival. While interspecific predation is common among mammalian carnivores, coyote predation of kit fox is among the highest reported between mammalian carnivores accounting for 50–76% of all known mortalities (Cypher and Spencer 1998, O'Farrell 1984, Palomares and Caro 1999, Ralls and White 1995). Predation rates during this study were within the previously reported range, with a majority of predation events occurring during pair formation (Nov–Feb).

Findings during this study were consistent with previous results where coyote predation was the dominant source of kit fox mortalities (O'Neal et al. 1987, Cypher and Spencer 1998, Cypher et al. 2000). The majority of mortality events occurred in the central portion of the study area, with most occurring south of the solar site. Coyote predations occurred throughout the study area, whereas 3 of 4 bobcat predations occurred in close proximity and may have been the result of a single male bobcat observed on multiple occasions in the vicinity of the predations.

The high proportion of predations occurring during pair formation accounts for consistently lower survival rates when compared to other seasons and the greatest effect on annual survival rates during this study. The overall survival rate during this study was 0.674, with a mean annual survival rate of 0.809. Annual survival rates in the Upper Chuckwalla Valley were within the previously reported range of 0.202–1.00 (Disney and Spiegel 1992, White and Ralls 1993, Cypher et al. 2000, Arjo et al. 2007, Moehrensclager et al. 2007, Nelson et al. 2007). While no predations events were recorded outside the known home range of the predated kit fox, the higher than expected predation rate during pair formation may be a result of mate searching by kit foxes.

Kit fox survival assessments are generally lacking across the range with the majority of studies conducted on the San Joaquin kit fox (Dempsey et al. 2014). Long-term studies have shown substantial inter-annual variation in adult kit fox survival rates, with adult kit fox survival rates negatively correlated to current and previous years leporid density, previous year composite prey indices, coyote visitation rates, and use of other food items (Cypher et al. 2000, Arjo et al. 2007).

Anthropogenic mortality sources (e.g., shooting, trapping, and vehicular strikes) were not a significant mortality source during this study, with a single kit fox mortality attributed to vehicular strike. Findings during this study are supported by previous research where anthropogenic mortality sources were identified, but not considered to adversely affect annual kit fox survival (White and Garrott 1999, Cypher et al. 2000, Cypher et al. 2009).

The presence of a utility-scale solar facility within the study area did not appear to have a significant effect on annual kit fox survival rates and was not a cause-specific mortality source. Radio-collared kit foxes were distributed throughout this study area with multiple individuals maintaining home ranges adjacent to and/or overlapping the solar facility (C. Randel, unpublished data), with no mortalities occurring as a result of construction or operation of the solar facility. While the conversion from native habitats to energy generation likely displaced resident kit foxes, it does not appear that, at the current development scale within this study area, kit fox survival was adversely affected.

## CHAPTER V

### CONCLUSIONS

This research provided regional estimates of desert kit fox life history parameters, thus filling regional knowledge gaps and providing the first estimates for desert kit fox populations in California. In the face of increasing development pressure in California's desert regions, specifically renewable energy development, estimates generated from this research can be used during environmental assessment and review, determining potential impacts to kit foxes resulting from development, and defining species specific mitigation measures.

Severe to extreme drought conditions may have indirectly influenced reproductive parameters as well as home range size during this study. Drought conditions are known to affect small mammal population dynamics and by association predators relying on small mammals as a primary food source (Cypher et al. 2000, White et al. 1996). Future research should investigate the causal factors influencing annual kit fox home range size in the Upper Chuckwalla Valley would require long-term research with period of normal, wet, and drought years. Research should additionally include prey resource estimates and how prey density influences distribution and use patterns during these same periods.

Coyotes were identified as the dominant predator of desert kit foxes during this study. While predation was the primary source of mortality during this study, desert kit foxes had annual survival estimates were similar to those previously reported. High annual



survival rates combined with reproductive rates  $>1$  indicated the study population was stable to increasing.

## LITERATURE CITED

- ADAMS, D.K., AND A.C. COMRIE. 1997. The North American monsoon. *Bulletin of the American Meteorological Society* 78:2197–2213.
- ARJO, W.M., E.M. GESE, T.J. BENNETT, AND A.J. KOZLOWSKI. 2007. Changes in kit fox-coyote-prey relationships in the Great Basin Desert, Utah. *Western North American Naturalist* 67:389–401.
- BEYER, H.L. 2012. Geospatial Modelling Environment (Version 0.7.2.0). (software).  
URL: <http://www.spatialecology.com/gme>.
- BIRD, L., M. BOLINGER, T. GAGLIANO, R. WISER, M. BROWN, AND B. PARSONS. 2005. Policies and market factors driving wind power and development in the United States. *Energy Policy* 33:1397–1407.
- BOWLES, A.E., J. FRANCINE, S. WISELY, J.S. YAEGER, AND L. MCCLENAGHAM. 1995. Effects of low-altitude aircraft overflights on the desert kit fox (*Vulpes macrotis arsipus*) and its small mammal prey on the Barry M. Goldwater Air Force Range, Arizona, 1991–1994. United States Air Force Research Laboratory Report Number AFRL-HE-WP-TR-2000-0101.
- CALIFORNIA ENERGY ALMANAC. Accessed 11 November 2014.  
[http://energyalmanac.ca.gov/electricity/total\\_system\\_power.html](http://energyalmanac.ca.gov/electricity/total_system_power.html).
- CARLISLE, J.E., S.L. KANE, D. SOLAN, AND J.C. JOE. 2014. Support for solar energy: examining sense of place and utility-scale development in California. *Energy Research & Social Science* 3:124–130.

- CLEVENGER, A.P., A.V. KOCIOLEK, AND B.L. CYPHER. 2010. Effects of four-land highways on desert kit fox and swift fox: inferences for the San Joaquin kit fox population. California Department of Transportation Technical Report CA10-1095, Sacramento, California, USA.
- CYPHER, B.L., AND J.H. SCRIVNER. 1992. Coyote control to protect endangered San Joaquin kit foxes at the Naval Petroleum Reserves, California. *In* Proceedings of the 15th Vertebrate Pest Conference, March 1992, Newport Beach, California. *Edited by* J.E. Borrecco and R.E. Marsh. University of California, Davis pp. 42–47.
- CYPHER, B.L., AND K.A. SPENCER. 1998. Competitive interactions between coyotes and San Joaquin kit foxes. *Journal of Mammalogy* 79:204–214.
- CYPHER, B.L., C.D. BJURLIN, AND J.L. NELSON. 2009. Effects of roads on endangered San Joaquin kit foxes. *Journal of Wildlife Management* 73:885–893.
- CYPHER, B.L., G.D. WARRICK, M.R.M. OTTEN, T.P. O'FARRELL, W.H. BERRY, C.E. HARRIS, T.T. KATO, P.M. MCCUE, J.H. SCRIVNER, AND B.W. ZOELICK. 2000. Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. *Wildlife Monographs* 145:1–43.
- CYPHER, B.L., M.E. KOOPMAN, AND D.R. MCCULLOUGH. 2001. Space use and movements by kit fox family members. *Transactions of the Western Section of the Wildlife Society* 37:84–87.
- DANEKE, D., M. SUNQUIST, AND S. BERWICK. 1984. Notes on kit fox biology in Utah. *Southwestern Naturalist* 29:361–362.

- DEMPSEY, S.J., E.M. GESE, AND B.M. KLUEVER. 2014. Finding a fox: an evaluation of survey methods to estimate abundance of a small desert carnivore. PLoS ONE 9:e105873.
- DENNIS, B., AND M.R.M. OTTEN. 2000. Joint effects of density dependence and rainfall on abundance of San Joaquin kit fox. Journal of Wildlife Management 64:388–400.
- DISNEY, M., AND L.K. SPIEGEL. 1992. Sources and rates of San Joaquin kit fox mortality in western Kern County, California. Transactions of the Western Section of the Wildlife Society 28:73–82.
- EGOSCUE, H.J. 1975. Population dynamics of the kit fox in western Utah. Bulletin of the Southern California Academy of Science 74:122–127.
- GIRARD, I. 2001. Field cost activity in the kit fox, *Vulpes macrotis*. Physiological and Biochemical Zoology 74:191–202.
- GOLIGHTLY, R.T., AND R.D. OHMART. 1983. Temperature of two desert canids: coyotes and kit foxes. Journal of Mammalogy 64:624–635.
- HIGGINS, R.W., W. SHI, AND C. HAIN. 2004. Relationship between Gulf of California moisture surveys and precipitation in the southwestern United States. Journal of Climate 17:2983–2997.
- HOLLAND, R.F. 1986. Preliminary descriptions of the terrestrial natural communities of California. California Department of Fish and Game, Sacramento, California, USA.

- KITCHEN, A.M., E.M. GESE, AND E.R. SCHAUSTER. 1999. Resource partitioning between coyotes and swift foxes: space, time and diet. *Canadian Journal of Zoology* 77:1645–1656.
- LIST, R., AND D.W. MACDONALD. 2003. Home range and habitat use of the kit fox (*Vulpes macrotis*) in a prairie dog (*Cynomys ludovicianus*) complex. *Journal of Zoology (London)* 259:1–5.
- LOPEZ, A., B. ROBERTS, D. HEILMILLER, N. BLAIR, AND G. PORRO. 2012. U.S. renewable energy technical potentials: a GIS-based analysis. National Renewable Energy Laboratory, Technical Report NREL/TP-6A20-51946.
- MCGREW, J.C. 1979. *Vulpes macrotis*. *Mammalian Species* 123: 1–6.
- MILLER, D.S., D.F. COVELL, R.G. MCLEAN, W.J. ADRIAN, M. NIEZGODA, J.M. GUSTAFSON, O.J. RONGSTAD, R.D. SCHULTZ, L.J. KIRK, AND T.J. QUAN. 2000. Serological survey for selected infectious disease agents in swift and kit foxes in the western United States. *Journal of Wildlife Diseases* 36:798–805.
- MILLSPAUGH, J.J., D.C. KESLER, R.W. KAYS, R.A. GITZEN, J.H. SCHULZ, C.T. ROTA, C.M. DONIOF, J.L. BELANT, AND B.J. KELLER. 2012. Wildlife radiotelemetry and remote monitoring. Pp. 258–283 *in* *Techniques for Wildlife Investigations and Management* 7<sup>th</sup> edition, Volume 1 (N.J. Silvy ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- MOEHRENSCHLAGER, A., R. LIST, AND D.W. MACDONALD. 2007. Escaping intraguild predation: Mexican kit foxes survival while coyotes and golden eagles kill Canadian swift foxes. *Journal of Mammalogy* 88:1029–1039.

- NATIONAL CLIMATE DATA CENTER. 2014. Historic Palmer Drought Indices.  
<<http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php>>.  
Accessed 2 January 2015.
- NELSON, J.L., B.L. CYPHER, C.D. BJURLIN, AND S. CREEL. 2007. Effects of habitat on competition between kit foxes and coyotes. *Journal of Wildlife Management* 71:1467–1475.
- O'FARRELL, T.P. 1984. Conservation of the endangered San Joaquin kit fox *Vulpes macrotis mutica* on the Naval Petroleum Reserves, California. *Acta Zoologica Fennica* 172:207–208.
- O'FARRELL, T.P., AND L. GILBERTSON. 1986. Ecology of the desert kit fox, *Vulpes macrotis arsipus*, in the Mojave Desert of southern California. *Southern California Academy of Sciences* 85:1–15.
- OLSON, T.L., AND F.G. LINDZEY. 2002. Swift fox survival and production in southeastern Wyoming. *Journal of Mammalogy* 83:199–206.
- O'NEAL, G.T., J.T. FLINDERS, AND W.P. CLARY. 1987. Behavioral ecology of the Nevada kit fox (*Vulpes macrotis nevadensis*) on a managed desert rangeland. *In* *Current Mammalogy. Edited by* H.H. Genoways, Plenum Press, New York. Pp 443–481.
- PALOMARES, F., AND T.M. CARO. 1999. Interspecific killing among mammalian carnivores. *American Naturalist* 153:492–508.
- POLLOCK, K.H., S.R. WINTERSTEIN, C.M. BUNCK, AND P.D. CURTIS. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53:7–15.

- R CORE TEAM. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org/>.
- RALLS, K., AND P.J. WHITE. 1995. Predation on San Joaquin kit foxes by larger canids. *Journal of Mammalogy* 76:723–729.
- RALLS, K., B. CYPHER, AND L.K. SPIEGEL. 2007. Social monogamy in kit foxes: formation, association, duration, and dissolution of mated pairs. *Journal of Mammalogy* 88:1439–1446
- SIKES, R.S., W.L. GANNON, AND THE ANIMAL CARE AND USE COMMITTEE OF THE AMERICAN SOCIETY OF MAMMALOGISTS. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy* 92:235–253.
- STANDLEY, W.G., W.H. BERRY, T.P. O'FARRELL, AND T.T. KATO. 1992. Mortality of San Joaquin kit fox (*Vulpes velox macrotis*) at Camp Roberts Army National Guard Training Site, California. U.S. Department of Energy Tropical Report No. EGG 10617-2157, EG and G/EM Santa Barbara Operations. National Technical Information Service, Springfield Virginia.
- U.S. DEPARTMENT OF ENERGY. 2014. 2013 Renewable Energy Data Book. United States Department of Energy, Washington D.C., USA.
- WESTERN REGIONAL CLIMATE CENTER. 2014. Climatological summary. Period of record: Jul 1996 to Dec 2008. <http://www.wrcc.dri.edu/summary/blh.ca.html> (accessed 14 September 2014).

- WHITE, P.J., AND K. RALLS. 1993. Reproduction and spacing patterns of kit foxes relative to changing prey availability. *Journal of Wildlife Management* 57:861–867.
- WHITE, P.J., AND R.A. GARROTT. 1997. Factors regulating kit fox populations. *Canadian Journal of Zoology* 75:1982–1988.
- WHITE, P.J., AND R.A. GARROTT. 1999. Population dynamics of kit foxes. *Canadian Journal of Zoology* 77:486–493.
- WHITE, P.J., C.A. VANDERBILT WHITE, AND K. RALLS. 1996. Functional and numerical responses of kit foxes to a short-term decline in mammalian prey. *Journal of Mammalogy* 77:370–376.
- WINTERSTEIN, C.M., K.H. POLLOCK, AND C.M. BUNCK. 2001. Analysis of survival data from radiotelemetry studies. In: Millspaugh, J.J., Marzluff, J.M. (Eds.), *Radio Tracking and Animal Populations*. Academic Press, San Diego, CA pp. 351–380.
- ZOELLICK, B.W., N.S. SMITH, AND R.S. HENRY. 1989. Habitat use and movements of desert kit foxes in western Arizona. *Journal of Wildlife Management* 53:955–961.
- ZOELLICK, B.W., AND N.S. SMITH. 1992. Size and spatial organization of home ranges of kit foxes in Arizona. *Journal of Mammalogy* 73:83–88.



## APPENDIX

Appendix 1. Seasonal (pair-formation, pup-rearing, dispersal) and annual radio-telemetry fixes for individual desert kit foxes.

ID	Sex	2012-2013				2013-2014			
		PF	PR	DSP	Annual	PF	PR	DSP	Annual
50212	M	11	-	-	11	-	-	-	-
363DE	F	73	94	33	200	75	98	-	173
40279	M	-	-	-	-	50	80	-	130
501CD	F	52	-	-	-	-	-	-	-
501D3	F	64	97	35	196	64	73	-	137
501D5	M	78	93	33	204	6	-	-	6
501D7	M	31	4	-	35	-	-	-	-
501D8	M	38	96	34	168	78	62	-	140
501DB	F	47	96	30	173	70	94	-	164
501DF	M	16	33	10	59	-	-	-	-
501E5	M	14	-	-	14	-	-	-	-
501EB	F	35	96	38	169	86	107	-	193
501EC	M	6	-	-	-	-	-	-	-
501ED	M	46	95	40	181	29	-	-	29
501F7	F	14	-	-	14	-	-	-	-
501FE	F	33	100	18	151	56	88	-	144
50204	F	34	-	-	-	-	-	-	-
50206	F	54	101	30	185	59	93	-	154
50219	F	71	85	25	181	62	-	-	62

Appendix 1 (cont.). Seasonal (pair-formation, pup-rearing, dispersal) and annual radio-telemetry fixes for individual desert kit foxes.

ID	Sex	2012-2013				2013-2014			
		PF	PR	DSP	Annual	PF	PR	DSP	Annual
5021A	M	52	93	40	185	75	109	-	184
50224	M	54	102	28	184	9	-	-	9
5022B	F	77	89	29	195	11	-	-	11
5022D	F	51	62	38	151	3	-	-	3
50426	F	-	-	-	-	66	85	-	151
5042C	F	-	-	-	-	57	71	-	128
5042E	F	-	-	-	-	16	11	-	27
50436	F	-	-	-	-	28	-	-	28
5044D	M	13	-	-	-	-	-	-	-
5047A	F	-	-	-	-	64	-	-	64
50480	F	-	-	-	-	85	99	-	184
50481	M	-	-	-	-	59	107	-	166
50625	M	80	93	29	202	67	58	-	125
50628	F	75	75	23	173	23	5	-	28
50633	F	8	-	-	8	-	-	-	-
50638	F	74	104	27	205	2	-	-	2
5063A	F	58	97	29	184	41	106	-	147
5063F	M	-	-	21	21	56	41	-	97
50641	F	70	88	12	170	-	-	-	-
50643	M	22	-	-	22	-	-	-	-

Appendix 1 (cont.). Seasonal (pair-formation, pup-rearing, dispersal) and annual radio-telemetry fixes for individual desert kit foxes.

ID	Sex	2012-2013				2013-2014			
		PF	PR	DSP	Annual	PF	PR	DSP	Annual
50647	F	75	100	16	191	-	71	-	71
5064E	M	73	91	34	198	67	63	-	130
50666	F	12	-	-	12	-	-	-	-
50668	M	75	90	21	186	52	74	-	126
5066D	M	91	68	-	159	-	-	-	-
50670	M	11	-	-	-	-	-	-	-
6448D	F	40	79	21	140	44	32	-	76
71221	M	65	23	-	89	-	-	-	-
73C30	M	58	76	44	178	64	25	-	89
73E46	M	26	68	33	127	60	3	-	63
73F3E	M	17	71	42	130	53	92	-	145
74BE7	F	49	94	38	181	75	52	-	127
84419	M	-	-	-	-	57	114	-	171
87119	F	33	35	-	68	-	-	-	-
8728B	M	49	86	28	163	81	87	-	168
B6031	F	20	36	34	90	57	30	-	87
B71FF	M	26	75	40	141	33	22	-	55